C

On the Structure of Teeth, and the resemblance of Ivory to Bone, as illustrated by microscopical examination of the Teeth of Man, and of various existing and extinct Animals. By Professor Owen, *F.R.S.*

Mr. Owen commenced by showing, that he had availed himself of the advantage afforded by the British Association, viz. that in the communications brought before a sectional committee, a fuller and more detailed retrospect of the progressive steps which have led to any remarkable discovery, is not only permissible, but peculiarly congenial to its general views and objects; and he therefore entered into a full detail of the recent investigations, especially those of Purkinje, Müller, and Retzius, on the intimate structure of the teeth, and particularly dwelt on the discoveries of the latter author, as regarded the structure of the human tooth. After describing the mode of arrangement of the particles of the earthy salts, which characterizes true bone, Professor Owen proceeded to state, that until a very recent period the analogy of tooth to bone was supposed to extend no further than related to the chemical composition of the hardening material, while the arrangement of this earthy constituent, as well as its mode of deposition during the growth of the entire tooth, were considered to be wholly different from that of bone, and to agree with the mode of growth of hair, and other so-called extra-vascular parts, with which teeth in general closely correspond in their vital properties. He observed, that the supposed proofs of the laminated structure of teeth, derived from the appearances presented by the teeth of growing animals, fed alternately with madder and ordinary food, and by those which often occur during the progress of decomposition of certain teeth, which are then resolved into a series of concentric or superimposed laminæ, were equally applicable to true bone, and were quite unavailable in illustrating the point under consideration; and that the appearances presented by the superficies of vertical sections of teeth, viewed with the naked eye or a low magnifying power, were due, not to the intervals of separate and superimposed lamellæ, but to the different refractions of light, caused by the parallel undulations or alternations of structure of minute tubes proceeding in a contrary direction to the supposed lamellæ. This apparent lamellated structure, however, is not constant, nor equally plain in different teeth; on the contrary, the fractured surface, or the polished section of the human and many other teeth, presents a silky or iridescent lustre, which has attracted the attention of several anatomists. Professor Owen observed, that Malpighi, in whose works may be detected the germs of several important anatomical truths, which have subsequently been matured and established, conceived that the teeth were composed of minute fibres reticularly interwoven; and Leewenhock, in

1683, had discovered that the apparent fibres of tooth were, in reality, minute tubes. The tubular structure of ivory was rediscovered by Purkinje and Fraenkel, in 1835, and the disposition of the tubes is accurately described and figured by them in the different kinds of human teeth. In these descriptions the tubes are spoken of according to their *prima facie* appearance as fibres, but their true nature is explained in different passages of the work*. Purkinje and Fraenkel also added to Dental Anatomy several new and interesting facts relating to the structure of the enamel, pointing out more especially the form and characteristic transverse striæ of the component crystals: and, lastly, they determined the true osseous nature of that distinct layer of substance which had been previously known to surround the fang in the teeth of man, and which they once observed to be continued upon the enamel of a human incisor. This observation, Mr. Owen proceeded to state, he had confirmed, and he exhibited several sections of the simple teeth of the Mammalia in which both the ivory and enamel were invested by a layer of osseous substance, identical in its structure with the cement which enters more abundantly into the composition of the compound teeth of the Herbivora.

The interesting experiments of Professor Müller, on the nature and contents of the *dental tubuli* were then noticed; and, lastly, a condensed analysis was given of the laborious and accurate microscopical observations of Professor Retzius, as related in the original Swedish memoir of that author on the structure of teeth. Besides confirming the fact, that the ivory or bony constituent of a human tooth consists of minute tubes lodged in a transparent medium, disposed in a radiated arrangement, with the lines proceeding in a direction perpendicular to the superficies of the tooth, Professor Retzius has more particularly observed and described the dichotomous branching of the primary tubes; the minuter ramuli sent off throughout the course of the main tubes into the clear interspaces; the calcigerous cells with which those fine branches communicate; the terminal ramifications of the tubuli, and their anastomoses with each other, and with calcigerous cells at the superficies of the ivory or bony part of the tooth. Professor Owen also discussed the opinion advanced by Professor Retzius, as to the function of this elaborate contexture of branched and anastomosing tubes and cells, in conveying, by capillary attraction, a slow current of nutritive or preservative fluid, through the entire substance of the tooth; which fluid might be derived either from the superficies of the pulp in the internal cavity of the tooth, or from the corpuscles or cells of the external layer of cortical substance or *cæmentum*,—with the tubes radiating from which corpuscles, the fine terminal tubes of the ivory anastomose. Professor Owen concluded the critical portion of his communication, by explaining the views entertained by Professor Retzius on the analogy subsisting between tooth and bone, which analogy he then proceeded to illustrate by his own observations on the structure of recent and fossil teeth.

* *De Penitiori Dentium Humanorum Structura Observationes.* Vratislaviæ, 1835.

With respect to the component structures of a tooth, Professor Owen commenced by observing, that in addition to those usually described and admitted, there were other substances entering into the composition of teeth, and presenting microscopic characters equally distinct both from ivory, enamel, and cement, and from true bone, and as easily recognisable.

One of these substances was characterized by being traversed throughout by numerous coarse canals, filled with a highly vascular medulla or pulp, sometimes anastomosing reticularly,—sometimes diverging, and frequently branching,—sometimes disposed nearly parallel with one another, and presenting more or fewer dichotomous divisions. The canals in many cases are surrounded by concentric lamellæ, and thus resemble very closely the Haversian canals of true bone; but the calcigerous tubes which everywhere radiate from them are relatively much larger. The highly-organized tooth-substance just described differs from true osseous substance, and from the cæmentum, in the absence of the Purkingian corpuscles or cells. This structure is exemplified in the teeth of many fishes and of some of the Edentate Mammalia.

Another component substance of tooth more closely resembles true bone and cement, inasmuch as the Purkingian cells are abundantly scattered through it; it differs, however, in the greater number and close parallel arrangement of the medullary canals. This structure is exhibited in the teeth of the *Megatherium*, *Mylodon*, and other extinct Edentata.

Mr. Owen then proceeded to describe the modifications of the abovementioned dental substanees in the teeth of different classes of the vertebrate animals, of which the following examples are selected.

1st. *Teeth of Fishes.*—With respect to this class, although the lowest of the vertebrate series, their teeth present in general the most highly organized condition, approximating most closely to the vascular character of true bone, and being in many species fixed by anchylosis or continuity of substance with the bones supporting them.

It was in the teeth of fishes that, in recent times, the tubular structure had been first recognised. Cuvier*, *e. g.* describes them as presenting three different structures, of whieh one kind (*les composées*) are formed of an infinity of tubes, all united and terminated by a common covering of enamel; of this kind he instances the tesselated teeth (*dents en forme de pavé*), as those of *Rays*.

Dr. Born also describes what he terms the "fibrous teeth of fishes," as being composed of hollow fibres†, and he compares these hollow fibres, or tubes, to those which enter into the composition of the teeth of the *Orycteropus*, &c.

The tubes here spoken of, as well as those mentioned by Cuvier, are sufficiently large to be distinguished by the naked eye; they do not, however, form the constituent texture of the teeth instanced, but only the coarser part of that texture. They contain a vascular medulla,

* Leçons d'Anat. Comp. 2d ed. tom. iii. p. 209.

† Heusinger's Zeitschrift, B. i. p. 184. "Die Faserzähne bestehen in ihrem Innern aus hohlen Fasern," &c.

and are the centres from which the true calcigerous tubes radiate, and they are, therefore, analogous to the simple pulp-canal of the human incisor, which, with its radiating microscopic calcigerous tubes, may be compared to a single medullary canal with its corresponding microscopic radiating tubes in the *Rays*, *Orycteropus*, &c.

Myliobatis.—A longitudinal section of a single dental plate, viewed by a low power of an inch focus, exhibits at its base a coarse network of large irregular canals, filled with a vascular medullary pulp. From this network smaller medullary canals proceed in a slightly-diverging course, subdividing dichotomously with interspaces equal to six or eight of their own diameters. In a transverse section of the tooth, seen under the same power, the area of the medullary canals is seen to present generally an elliptical form, from which radiating calcigerous tubes are faintly perceptible. Each canal and its series of tubes is surrounded by a line of generally an hexagonal form, and which constitutes the boundary between contiguous canals and tubes, the whole tooth being thus composed of an aggregate of simple elongated, commonly six-sided prismatic teeth, placed vertically to the grinding surface. A section through the roots of the tooth shows that these parts are occupied by a network of irregular canals, which anastomose by arched branches with the network of the contiguous root, and these with the network of coarser tubes which occupy the basis of the tooth for an extent exceeding the length of the root itself.

With a higher power, $\frac{1}{10}$th inch focus, the calcigerous tubes are seen to radiate in all directions from the medullary canals, and are sent off throughout the whole course of the canal. The tubes are short, wavy, richly arborescent, and form numerous anastomoses with each other. The transverse sections of the tooth show that the area of each medullary canal has been filled up or diminished by the deposition of a series of concentric lamellæ.

The ramification of the tubes in this tooth presents the same general character as those of *Acrodus*, but they are shorter, and each group in the transverse section is separated from the contiguous one by the regular boundary lines above-mentioned, which distinguish the teeth of the *Myliobatis* from those of the *Acrodus*, *Psammodus*, *Cestracion*, or any of the shark tribe. The tooth of the *Orycteropus* is that which has the nearest resemblance to the tooth of the *Myliobatis*.

Acrodus nobilis.—The crushing teeth of this extinct genus are composed of two substances, viz. a thin external almost colourless layer, which represents the enamel, and an amber-coloured coarser ivory composing the body of the tooth, and continuous with and passing into the coarse cellular bony basis and support of the tooth. Microscopic sections of this tooth afford the most beautiful appearances, and, perhaps, the most instructive illustration of the relation of ivory to bone. The body of the tooth consists of groups of beautifully branched and irregularly wavy medullary canals imbedded in a clear matrix. These canals are surrounded by concentric strata, and closely resemble the canals of Havers in true bone. The calcigerous tubes, which radiate from the medullary canals, have a graceful undulatory course and are

much branched; but towards the periphery of the tooth, the ramified tubes are all directed, as in true ivory, at right angles to the superficies, and thus constitute a regular layer of calcigerous tubes, disposed so as to offer the greatest resistance to pressure. This layer is equal in thickness to about one-fifteenth part of the vertical diameter of the thickest part of the tooth.

The finest or terminal branches of this peripheral layer of tubes, I have traced in various places into what at first sight appears to be the enamel. Under a magnifying power of 400 diameters, however, this outermost layer is seen to be composed of extremely minute tubes, $\frac{1}{1000}$th of a line in diameter; they are branched like the coarser tubes of the body of the tooth; irregularly wavy in their course; having a general tendency to an arrangement at right angles to the superficies, but inextricably interwoven, and connected anastomotically together, so as to require a strong light to penetrate even the thinnest section, and render their structure and arrangement visible. The continuation of these finer superficial tubes, with the coarser tubes of the body of the tooth, is best observed by changing the focus, which brings the transitional tubes at different depths in the section into view. In some parts of the section, a medullary or Haversian canal is displayed longitudinally; and the parallel lines of the surrounding concentric strata on each side are exhibited. The canal maintains a general uniform diameter, but slightly dilates where it divides or sends off a cross branch to communicate with the adjoining canals. These canals commence from the large cells of the bone of the base, and pass into the substance of the tooth towards its periphery; communicate by transverse canals, but all ultimately terminate in bundles of the wavy ramified calcigerous tubes of the body of the tooth. I conclude that the coarser canals were occupied by a vascular pulp in the living animal, and that the fine terminal tubes were the seat of the salts of lime. The silex occupying the longitudinal canals and coarser tubes, has received a dark stain, probably from the colouring matter of the vascular pulp,—but the finer tubes, from the want of this difference of colour, are in many parts obscurely visible, if at all. They are discernible in some situations crossing the concentric lamellæ at right angles to the central canal. The chief difference between the appearance presented by the Haversian canals of the tooth of Acrodus, and those in true bone, is in the absence of the cells or corpuscles. These are apparent only at the base of the tooth—irregular in size and form, very minute, and appearing like simple granules without radiating lines. The character of the main or coarser canals and calcigerous tubes of the ivory of the tooth of Acrodus, reposes on their undulating course, their rapid diminution and branching, and the moderately acute angles at which the branches are given off, except at the circumference of the tooth, where they run nearly parallel to each other. In other parts they closely resemble the branching of trees. The line of demarcation between the coarser and finer ivory is formed by a series of small cells of a similar granular appearance to those at the base, in which many of the finer branches of the coarse ivory terminate, and from which the minute tubes of the enamel-like

ivory commence. The superficies of the tooth is slightly punctated, but the depressions do not correspond with the mouths of tubes, but with the interspaces of whole groups of the coarser tubes.

Psammodus.—A transverse section of the tooth of this genus presents the appearance, under a moderate magnifying power, as if it were composed of close set coarse tubes, the areæ of which were thus exposed. Such a section, viewed with a power of 400 diameters, shows that these tubes are surrounded by concentric lamellæ, exactly as the Haversian canals; and that these lamellæ, and the clear interspace, which is generally equal to the thickness of the lamellæ, are permeated by minute irregularly disposed tubes, which anastomose in the clear interspace, and open into extremely minute cells, scattered in the same part. A longitudinal section of the same tooth shows the whole course of the canals; they run nearly perpendicularly to the convex superficies of the tooth, and, consequently, incline outwards at the sides of the section. They lie nearly parallel with each other, with interspaces equal to from 6 to 8 times their own diameter, and branch dichotomously once or twice in their course. Each canal is surrounded by concentric layers of a dark colour, encroaching upon one-third of the interspace, which thus presents two dark streaks and one intermediate right line: the whole of these interspaces is perforated by the irregular wavy, branched, anastomosing calcigerous tubes. The terminations of the canals near the periphery of the tooth are slightly dilated, and give off in every direction calcigerous tubes corresponding to those in the interspace of the canals. The structure of the tooth of *Psammodus* differs from that of *Acrodus* in the greater number and more parallel course of the canals, their fewer branches, and want of anastomoses, and in the absence of a distinct external enamel-like layer of very fine tubes.

Ptychodus latissimus.—The structure of this tooth has a close affinity to that of *Psammodus*: it is composed of Haversian canals and calcigerous tubes proceeding therefrom. The base of the tooth is composed of close-set and irregular canals, and is very opaque: the canals emerge from this part half-way to the grinding surface, to which they proceed perpendicularly. They differ from those of the *Psammodus* in being wider, more close-set, and more branched,—the branches being given off at more open angles, and the terminal ones being larger in proportion to the trunks. The papillose surface of the tooth is composed of the terminations of the inextricably interwoven fine calcigerous tubes given off from the terminations of the canals. The interspaces of the canals are also occupied by the same minute anastomosing reticulate tube-work. Numerous minute calcigerous cells are also present in the interspaces. There is a clear substance coating the grinding surface of the tooth, in which neither tubes nor any definite structure could be detected, though, from analogy, such doubtless exist. The darker substance, forming the concentric lamellæ around the canals, occupies the same proportion of their interspace as in the *Psammodus*.

Chimæra.—The tooth of this fish appears, when a section of it is

viewed with the naked eye, to be composed of a close-set series of parallel coarse tubes, dividing dichotomously, and united together here and there by short transverse arches with the convexity towards the grinding surface. The diameter of the interspaces of these canals is generally equal to between two and three diameters of their areæ.

Viewed by a higher power, the tubes are seen to be immediately surrounded by a clear amber-coloured substance, analogous to that which forms the concentric layers around the canals, which I have compared to those described by Havers in true bone.

Under a power of 400, the large canals are seen to send off from every part of their course numerous minute tubes, generally at right angles, to the medullary canals; these tubes run irregularly, ramify, and anastomose in the interspaces of the medullary canals, and form a coarse matting or plexus of tubes, the number of which sometimes quite intercepts the light.

In the teeth of the genus *Lamna,* a number of medullary canals are continued from the short and small pulp-cavity at the base of the tooth, which ramify and anastomose, so as to form a beautiful reticulate arrangement of tubes, very similar to a network of capillary vessels, throughout the whole substance of the tooth: they ultimately terminate in a flattened sinus, which seems to extend over the whole tooth at a very short distance from its superficies. The whole of the superficial part of the tooth is occupied by minute calcigerous tubes, which proceed in a wavy course, generally at right angles to the external surface; they ramify, and their terminal branches anastomose, and many of them terminate in a stratum of calcigerous cells, situated between the body of the tooth and what appears to be the outer stratum of enamel. In this stratum, however, there are evident traces of a series of much finer tubes, continued from the preceding layer of cells, which proves that this is not true enamel, but a fine kind of ivory, like that in the tooth of the sloth and megatherium. The coarse reticulate canals in the body of the tooth are surrounded by concentric layers, traversed by the calcigerous tubes which are everywhere given off at right angles from the larger canals; these canals are occupied, in the recent fish, by a sanguineous medulla, closely resembling that which fills the medullary cells of the coarse bone, to which the base of the tooth is anchylosed, and with which cells the anastomosing reticulate canals of the tooth are directly continuous.

Carcharias Megalodon.—The calcigerous tubes at the superficies of this tooth are disposed in groups which, with an insufficient magnifying power, appear like single coarse tubes, but with a higher power, are seen to be composed of congeries of parallel tubes, apparently twisted together. The interspaces are nearly equal to the diameter of these curious fasciculi: they are occupied by more scattered tubes, and by short oblique or transverse anastomosing branches. At one part of a section of this tooth, the peripheral coarse sinus or canal, which always runs parallel with the superficies, gave off an infinite number of minute tubes, which formed a plexus, (or plexiform stratum,) and from the outer part of this plexus, the tubes above described passed, at right

angles, to the surface. In the longitudinal section of this tooth, the twisted appearance, above described, of the peripheral calcigerous tubes, was seen to be due to the number of side branches given off at an acute angle to the main tube. At the apex the tubes radiate, and suddenly diverge to proceed transversely to the sides. In the body of the tooth the main canals are surrounded by concentric lamellæ, traversed by radiating and anastomosing calcigerous tubes, which form a fine network in the interspaces.

Dictyodus, a *sphyrenoid genus*.—The body of the conical maxillary teeth of this fossil species presents a beautiful assemblage of medullary canals, having a general parallel course from the basis to the apex, dividing and subdividing as they approach the latter, with interspaces generally equal to three or four of their own diameters, and anastomosing by short branches crossing the interspaces, and thus intercepting quadrangular, sub-elliptical, pentagonal, or hexagonal spaces, elongated in the axis of the tooth, but becoming shorter as they approach the apex, which presents the appearance of a coarse irregular lace-work. The interior of some of the larger canals is occupied with a granular matter.

I have been able to detect the fine calcigerous tubes only at the circumference of the tooth radiating from the peripheral side of the superficial canal into the clear enamel-like coating of the tooth. They immediately begin to ramify at acute angles.

The larger canals are continued directly from the coarse medullary cells at the bony base of the tooth: the longitudinal ones are mostly larger than the transverse or oblique short anastomosing canals. This tooth resembles in general structure that of the *Anarrhichas Lupus*.

The round pharyngeal teeth of the extinct genus *Sphærodus* are anchylosed to a bone of a cellular structure. The body of the tooth consists of coarse tubes, which arise insensibly from the basis, where they have a diameter of $\frac{1}{3500}$th of an inch, and proceed directly and perpendicularly to the surface of the tooth. The characteristics of these tubes are, first, that they are so closely arranged together, that only one-fourth of their own diameter intervenes between them at their origins. Secondly, they present the appearance of a closely-twisted bundle of smaller tubes, and begin immediately to give off short and somewhat coarse branches at very acute angles; these branches increase in number, and the trunks proportionally diminish, until they have traversed two-thirds of the vertical diameter of the tooth; they resolve themselves into fasciculi of extremely minute twigs, which interlace together, and in many places dilate into, or communicate with, numerous minute calcigerous cells, and form so dense a layer as to intercept the light, excepting towards the circumference of the tooth, and consequently at the two extremities of the section, where only the structure above described is visible. Several small twigs pass beyond this plexus into the clear enamel-like outer layer of the tooth, in some parts of which traces are perceptible of a plexus of still more minute tubes, or *striæ*, which gradually diminished until they escaped the highest magnifying power employed in this examination.

Lepidotus.—The pharyngeal teeth of some of the species of this

genus, *e. g. Lepid. Fittoni*, correspond so closely in size and form with those of the preceding genus, (*Sphærodus*,) as not to be distinguishable from them but by a comparison of their microscopic structure. They are composed of fasciculate tubes continued directly from the cells of the osseous base, radiating, with a direction vertical to the surface of the tooth, and giving off branches, at an acute angle, from their very commencement: thus far the general character of the texture of the tooth is the same; but the fine branches into which the fasciculate tubes resolve themselves, diverge at a much more open angle from the main trunk, are spread out more widely, have a more wavy course, and present the appearance of corn beaten down with heavy rain. These five terminal branches are inextricably interwoven, and present the appearance of numerous anastomoses, but do not form so dense a structure as to intercept the light, as is the case in the teeth of *Sphærodus*.

Gyrodus.—In the pharyngeal teeth of this genus, the tendency to the structure of the dense ivory of the teeth of the higher *vertebrata*, which is obvious in the teeth of *Sphærodus* and *Lepidotus*, is carried on to a close correspondence. The base of the tooth is excavated by a large and simple pulp-cavity, presenting a quadrate figure in a vertical section of the tooth; this cavity is immediately continuous with the large cells and reticulate canals of the bony base. The body of the tooth consists of close-set minute calcigerous tubes, having a diameter of $\frac{1}{700}$th of a line at their origin, radiating in a direct line, but with a minute and regularly undulating course, and a gradually diminishing diameter to the superficies: the lateral tubes pass horizontally, those continued from the summit of the pulp-cavity vertically, to the grinding surface. They give off very regular, but extremely minute branches, which are lost in the clear and dense enamel-like superficial layer of the tooth.

Barbel. Pharyngeal tooth.—In this tooth the structure characteristic of the ivory of the simple mammalian tooth is beautifully displayed. The cavity of the pulp is single, elongated and narrow, and the tubes radiate to the surface of the tooth at right angles to that surface, and chiefly, therefore at right angles to the axis of the tooth. The tubes are minute and numerous, beautifully and regularly undulating, seldom dividing, and then dichotomously, each branch proceeding nearly in the direction of the trunk. A detached fossil pharyngeal tooth of this kind would be distinguishable from a mammalian carnivorous tooth of similar form by the circumstance, that in the tooth of the fish the pulp-cavity becomes directly continuous with the coarse cells and medullary canals of the bone with which it is anchylosed; the base of the tooth is not diminished to a fang, and the calcigerous tubes are larger and more irregular the closer they are to the base of the tooth.

The large conical carnivorous teeth of the extinct genera *Holoptychus* and *Megalichthys* present a similar grade of structure to that of the pharyngeal tooth above described. The whole body of the tooth is here composed of minute close-set calcigerous tubes, having a diameter of $\frac{1}{1500}$th of a line in diameter, with interspaces of nearly twice that diameter. The calcigerous tubes have a minutely undulated course,

and pass in nearly a straight line from the internal to the external surface of the tooth: the pulp-cavity extends about half-way through the body of the tooth, and has a narrow elliptic transverse section; it becomes gradually smaller at the base of the tooth, and there branches out into several processes, which are continued into the cylindrical processes of the dental substance, which are imbedded, like so many piles, in the coarse osseous texture of the jaw. It is this peculiar mode of fixation of the tooth to the jaw-bone that would serve at once to distinguish the tooth of *Holoptychus* from that of any saurian or mammiferous species which it might resemble in external form.

In not any of the teeth of fishes above described was there an external covering of enamel, presenting the characteristic transversely-striated prismatic crystalline structure which distinguishes the enamel of the higher Vertebrata. In all cases, where structure could be detected in the dense exterior layer representing the enamel, it presented the organized tubular character, differing from the subjacent ivory only in the more minute size of the tubes.

Of the teeth of reptiles, Prof. Owen described those of several genera, recent and fossil. In the *Sharp-nosed Alligator* (*Crocodilus acutus*), the exposed part of the tooth is covered with true enamel, and that part which is lodged in the socket is coated with a layer of *cæmentum*. The tubuli are very fine, not exceeding at the widest part $\frac{1}{1000}$th of a line. With a low magnifying power they appear to radiate in straight lines from the *cavitas pulpi* to the superficies of the tooth, proceeding at right angles to that surface: under a higher power, they are seen to be slightly undulating, and to have interspaces equal to five times their own diameters. The main tubes begin to divide soon after their origin, and the branches diverge from each other; these send off numerous finer ramuli, which are generally turned towards the root: these terminate or dilate, in many places, into calcigerous cells, which form numerous layers, generally arranged parallel with the contour of the cavity of the pulp, and most numerous at the circumference of the ivory. It is to these layers of calcigerous cells, and to the parallel curvatures of the tubes, that the apparent laminated structure is seen to be due, when sections of these teeth are examined with a low magnifying power. A thin membrane lines the cavity of the pulp of even the oldest teeth.

The fossil teeth of the extinct Reptiles reveal an equally complicated structure. The fang of the fluted teeth of the *Ichthyosaurus* is covered with a thick layer of *cæmentum*, which fills the interstices of the grooves. The tubuli of the ivory-constituent are extremely minute; they resemble in their arrangement and ramification those of the crocodile, but the undulations are more numerous and more marked.

In the *Iguanodon*, the ivory is composed of close-set tubes, radiating in a wavy course from the *cavitas pulpi* to the superficies: each tube is also minutely undulating. They are coarser than those of the Ichthyosaurus; and the ivory further differs in the presence of large medullary canals, which are seen here and there radiating from the cavity of the pulp, and traversing the dense ivory.

In the class *Mammalia* the teeth of the animals belonging to the order called *Edentata* by Cuvier, present the nearest resemblance to the vascular and organized structures above described in the teeth of cartilaginous fishes. The close resemblance, in this respect, between the teeth of *Orycteropus* and *Myliobatis* has already been alluded to, but their outward form and mode of attachment are widely different. The teeth of *Orycteropus* present the form either of a simple cylinder, or of two joined laterally together. In these, as in the tesselated teeth of the *Rays*, Cuvier had recognised a tubular structure; but the tubes described by that great anatomist were merely the medullary or pulp-canals which run parallel with the axis of the tooth, at regular distances from each other. These visible medullary canals, which are widest at the base of the tooth, diminish at first rapidly, and afterwards very gradually in diameter, and some of them divide dichotomously in their course from the base to the grinding-surface of the tooth. Throughout their course they send off at right angles and from every part of their circumference the true calcigerous dental tubes. These tubes, at their origin are $\frac{1}{700}$th of a line in diameter, but quickly diminish, as they proceed in a wavy course to the interspace which divides them from the contiguous medullary canals and their systems of calcigerous tubes: the tubes give off numerous branches, which form, near the boundary space, a moss-like reticulation of extremely fine tubes. Nearly the whole extent of the medullary canal is occupied with a vascular pulp, and its parietes near the base is likewise surrounded with a thin vascular capsule; the whole tooth is in fact composed of a closely-packed congeries of slender prismatic elongated miniature simple teeth, each of which is provided with its pulp and capsule, its medullary cavity, and its radiated series of calcigerous tubes. The capsule of each component prismatic tooth becomes ossified at a little distance from the base of the tooth. A transverse section of the whole compound tooth above this part presents a series of hexagonal, pentagonal, or tetragonal groups of calcigerous tubes radiating from an elliptical space occupied by a vascular pulp, and separated from each other by a thin boundary line of bone or *cæmentum*, characterized by the presence of Purkingian corpuscles. The vascular pulp, likewise, becomes ossified near the grinding-surface of the tooth, and consequently a transverse section taken near this part presents the centres of the radiation of the calcigerous tubes filled up with bone or *cæmentum*.

Bradypus didactylus.—The substance in the tooth of this species which corresponds to the true ivory forms only a very thin layer, situated near the superficies of the tooth; the central yellowish substance of the tooth presents a number of coarse canals, about one-tenth of a line in diameter; these radiate in a beautiful manner from the upper part of the pulp-cavity, those in the middle proceeding parallel to the axis of the tooth, those at the circumference curving outwards. These canals are unequal, presenting partial dilatations, which, however, are sometimes, though rarely, discernible in the tubuli of human teeth; they give off numerous tortuous branches of different sizes, and these open into very distinct calcigerous cells scattered about the interspaces

of the coarser canals. The fine crust of ivory above mentioned is formed by minute tubes directly continued from the finer ramifications of the large canals of the central substance, and terminated in plexus of still finer tubes, which at length escape the highest magnifying powers. The fang, or inserted part of the tooth, of the sloth is coated with a layer of *crusta petrosa*, which is characterized by large canals and abundant *Purkingian corpuscles*. There is no enamel in the composition of these teeth or of those of any of the existing Edentata.

Megatherium.—Microscopic examinations of the structure of the tooth of this extinct mammifer have undeceived me with respect to its conformation; the thin dense layer between the crusta petrosa and the internal substance composing the body of the tooth is not enamel, but a layer of ivory composed, like the dense ivory of the teeth of other Mammalia, of minute tubes having a parallel course at right angles to the surface, and minutely undulating in that course, and corresponding with the thin cylinder of true ivory in the tooth of the sloth. The central part of the body of the tooth consists of a coarser ivory, much resembling the teeth of *Psammodus* or *Myliobatis*, among fishes. It is traversed by large medullary canals parallel to each other and to the finer ivory tubes, having angular interspaces equal to one and a half diameter of their own area, and generally anastomosing in pairs by a loop whose convexity is close to the origin of the fine ivory tubes, as if each pair so joined was composed of one reflected canal. Some, however, are continued across the fine ivory, and anastomose with the corresponding canals of the *cæmentum*; the interspaces of the coarse ivory tubes appear at first view granular, but they are principally occupied by reticular branches given off from the canals: some of these anastomosing branches are seen coming off from the concavity of the loops, and retrograding. Numerous minute cells are scattered about the terminal loops of the medullary canals of the coarser ivory. The origin of the fine ivory tubes is from the convexity of the peripheral loops of the above medullary canals. The ivory tubes are separated by interspaces equal to one and a half their own diameter; they divide and subdivide, growing smaller and more wavy towards the periphery or *cæmentum*; here their terminal branches assume a bent direction, and form anastomoses, dilate into small cells, and many are clearly seen to become continuous with the radiating fibres or tubes of the corpuscles of the contiguous *cæmentum*. The cement is traversed by large canals running, like the canals of the coarse ivory, parallel to each other and to the course of the fine ivory tubes, with interspaces of about five times their own diameter, occasionally, but rarely, dividing dichotomously,—in which case the branches usually anastomose and form loops with the convexities towards and close to the outer layer of fine calcigerous cells, in which the fine ivory tubes terminate. The cement differs from the coarse ivory in the fewer number of canals, and more especially by the presence of the bone corpuscles or radiated cells in the interspaces of the canals. The irregular tortuous fine tubes forming a network in the interspaces, and especially those proceeding from the convexities of the loops, are much more distinct than the correspond-

ing tubes in the coarse ivory. The primary branches of the canals go off generally at right angles. In a few places I have distinctly seen the large canals of the *cæmentum* traversing the substance of the fine ivory to anastomose with those of the central coarse ivory.

We have thus, then, in the tooth of the *Megatherium*, an unequivocal example of a course of nourishment of the teeth distinct from and superadded to that which proceeds from the surface of the pulp and the cavity of the fang in which it is lodged, viz. by a direct communication between the vascular canals of the external organized *cæmentum* and the tubuli of the ivory. *Retzius* observes of the human tooth, that "the fine tubes of the *cæmentum* enter into immediate communications with the cells and tubes of the ivory, so that this part can obtain from without the requisite humours after the central pulp has almost ceased to exist." In the Megatherium, however, those anastomoses have not to perform a vicarious office, since the pulp maintains its full size and functional activity during the whole period of the animal's existence. It relates to the higher organized condition, and doubtless to the higher vitality of the entire grinder in that extinct species.

The views entertained by Cuvier of the affinity of *Megatherium* to *Bradypus*, derive full confirmation from the microscopic investigation of its teeth. It needs but to compare the preceding description with that published by Retzius of the structure of the teeth of the *Armadillo*, to perceive how much more closely the Megathere resembles the Sloth in the structure of its teeth. The Megatherium has ten teeth in the upper jaw, five on each side; differing slightly in form and size, but all presenting the same characteristic vascular structure as above described. The structure of the coarse central ivory may be compared with that of which the entire tooth of the Orycteropus is composed, with these differences,—first, that the parallel medullary canals and their systems of calcigerous tubes are not separated from their neighbours by a layer of *cæmentum*, and, secondly, that the medullary canals anastomose at their peripheral extremities.

Toxodon.—The teeth of this extinct animal have an external but incomplete investment of enamel, which is deficient for a small extent at the anterior and posterior surfaces of the tooth; but these parts, as well as the enamel, are covered with a thin exterior layer of *cæmentum*. The body of the tooth is composed throughout of compact ivory, consisting of minute wavy calcigerous tubes, $\frac{1}{500}$th of a line in diameter at their origin, which radiate in directions vertical to the superficies of the tooth, or of the inflected fold of enamel, from the central pulp-cavity.

In the discontinuity of the enamel surrounding the ivory of the tooth, the Toxodon differs from all known Pachyderms, and exhibits an approach to the *Rodentia* and *Edentata*.

In the *Leopard*, the tubuli of the canine teeth are chiefly remarkable for the number of their ramifications, and the beautiful curvatures of the same. In the *Mole*, the main tubes are remarkable for their width and shortness; they are as large at their commencement as in the human tooth, but soon divide at their extremities into a number of smaller branches, which again subdivide, the terminal twigs anasto-

mosing and communicating with minute calcigerous cells immediately beneath the enamel.

The teeth of those orders of Mammalia in which they present the usual structure of compact ivory, enamel, and *cæmentum*, have been described in several genera with so much accuracy by Professor *Retzius*, that there are few modifications or examples worthy of particular attention.

In the simple teeth of the Marsupial animals, the external layer of *cæmentum* covering the enamelled crown is thicker in many of the species than is usually seen. The Phalangers, Koala, and Wombat, offer good examples of the superficial layer of cement on the exposed crown. It possesses the usual high degree of organization, and abounds in the Purkingian cells.

In the incisors of the Orang-Utan, the main calcigerous tubes of the ivory, which radiate from the central cavity of the pulp, are somewhat larger than those of man; they present the same primary curvatures, but less numerous and less strongly-marked secondary undulations*. In the crown of the tooth of the Orang, the dental tubes are chiefly branched at their extremities, while towards the apex of the fang the main tubes are surrounded by exceedingly fine and close-set branches, which subdivide in their course. The nearer the crown, the larger are these branches; they are curved, with the concavity towards the pulp.

In the summary of this series of observations which Professor Owen detailed, he observed, that in the human and similarly organized teeth, the analogy of ivory to bone, as to texture, was only seen in the existence and intercommunication of the minute calcigerous tubes and cells; but that there was no trace of medullary or Haversian canals, with their characteristic concentric laminæ, unless the entire tooth were regarded as analogous to a single enlarged Haversian canal, when the cavity of the simple pulp would represent the medullary cavity of the canal; while the tubes, with the appearance of laminæ occasioned by their undulations, might be deemed equivalent to the concentric lamellæ and the calcigerous tubes, which, in bone, traverse these lamellæ, and radiate from the Haversian canal. In the teeth of many of the lower animals, however, and especially that of the extinct *Acrodus*, amongst the cartilaginous fishes, the resemblance of the dental tissue to bone was extended to the existence of the characteristic Haversian canals in great numbers. The presence of these canals was explained by the progress of the development of these bone-like teeth, as observed by Professor Owen in recent cartilaginous fishes. The large pulp, at the commencement of the formation of the tooth, had exercised its ordinary function in the secretion of a close-set series of calcigerous

* The primary curvatures Professor Owen explained to be those which belong to the general course of the dental tube, and which are seen with a lower power; in man they resemble the curves of the Greek Zeta (ζ). The secondary curves are minute undulations in the whole course of the tube, requiring a high power for their perception, and affecting both the main trunks and their branches; these probably indicate and are due to the movements of the formative pulp during the deposition of the ivory.

tubes, having a general direction perpendicular to the surface of the tooth, and closely resembling true ivory. The pulp then, instead of continuing to form similar tubular ivory, by adding to the extremities of the previously formed tubes, became subdivided, or broken up into numerous processes, to which those forming the three fangs of a human grinder are analogous. But each process here becomes the centre of an active formation of similar branched tubes, radiating in all directions from that centre, and anastomosing by their peripheral branches with those from contiguous centres, or communicating with interposed calcigerous cells. The cavities containing the above subdivisions of the pulp, like the Haversian canals containing the processes of medulla in true bone, have had their area diminished in like manner by the successive formation of a series of concentric lamellæ, traversed, as in true bone, by radiating and minutely ramified calcigerous tubes, communicating with each other and with the minute cells in the interspaces. The resemblance between the pulp canals of the teeth of *Acrodus* and of the medullary canals of bones, is further exemplified in the existence of lateral communications in teeth; and in function as well as structure they may be regarded as being identical.

With reference to the application of the tubular structure of the teeth to the explanation of their pathology, Professor Owen observed, that it was a new and fertile field, which would doubtless be replete with interesting results, and might suggest some good practical improvements in dental surgery. Ordinary decay of the teeth commenced, in the majority of instances, immediately beneath the enamel, in the fine ramifications of the peripheral extremities of the tubes, and proceeded in the direction of the main tubes, and, consequently, by the most direct route to the cavity of the pulp. The decayed substance, in some instances, retains the characteristic tubular structure, which is also observable in the animal basis of healthy teeth after the artificial removal of the earthy salts. The soft condition of the decayed portion of a tooth is well known to all dentists; it depends upon the removal of the earthy salts from the containing tubes and cells, in which process the decay of teeth essentially consists. The main object of the dentist, in reference to ordinary caries of the teeth, seems, therefore, to be, to detect those appearances in the enamel which indicate the commencement of decay—to break away the enamel, whose natural adhesion to the subjacent softened ivory will be found to be more or less diminished—to remove the softened portion of the ivory and fill up the cavity with incorrodible substance. Experience proves, what could not be intelligibly explained before the true structure of the dental substance was known, viz. that the progress of the decay is sometimes thus permanently arrested. Such cases sometimes exhibit a thin dense layer of ivory in contact with the stopping, apparently resulting from an exudation of the calcareous salts from the extremities of the tubes divided in the operation.

In conclusion, Professor Owen passed in general review over the structures which he had described in detail. He particularly pointed out the important application of the microscopic examination of thin

slices of fossil teeth to a determination of the natural family, or genus, to which such teeth had belonged, when other characters fail, or a complete tooth is unattainable. Finally, Mr. Owen remarked, that through the endless diversity which the microscopic texture of the teeth of different animals presented, the universal law of the tubular structure could be unequivocally traced; and that the general tendency of the modifications observable in descending from man to the lower classes of the vertebrate animals, was a nearer approximation of the substance of the tooth to the vascular and organized texture of bone.

[From the EIGHTH REPORT of the BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.]

PRINTED BY RICHARD AND JOHN E. TAYLOR,
RED LION COURT, FLEET STREET.